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EMI in a Hybrid Electric World

Tactical Wheeled Vehicles Conference

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BAE SYSTEMS Platform Solutions

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Agenda

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- Definition of EMI / EMC
- EMI specifications
- Test methods and set-ups
- Emissions tutorial
- Susceptibility tutorial
- EMI Considerations for Hybrid Electric systems
- Questions & (hopefully) Answers

What Is EMI / EMC?

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- EMI - Electromagnetic Interference is any electric or magnetic emission from a device or system that interferes with the normal operation of another device or system.
- EMC - Electromagnetic Compatibility is the ability of a device or system to function without error (susceptibility) in its intended electromagnetic environment.

EMI / EMC is not Black Magic!

EMI / EMC is Throughout the C4ISR Environment

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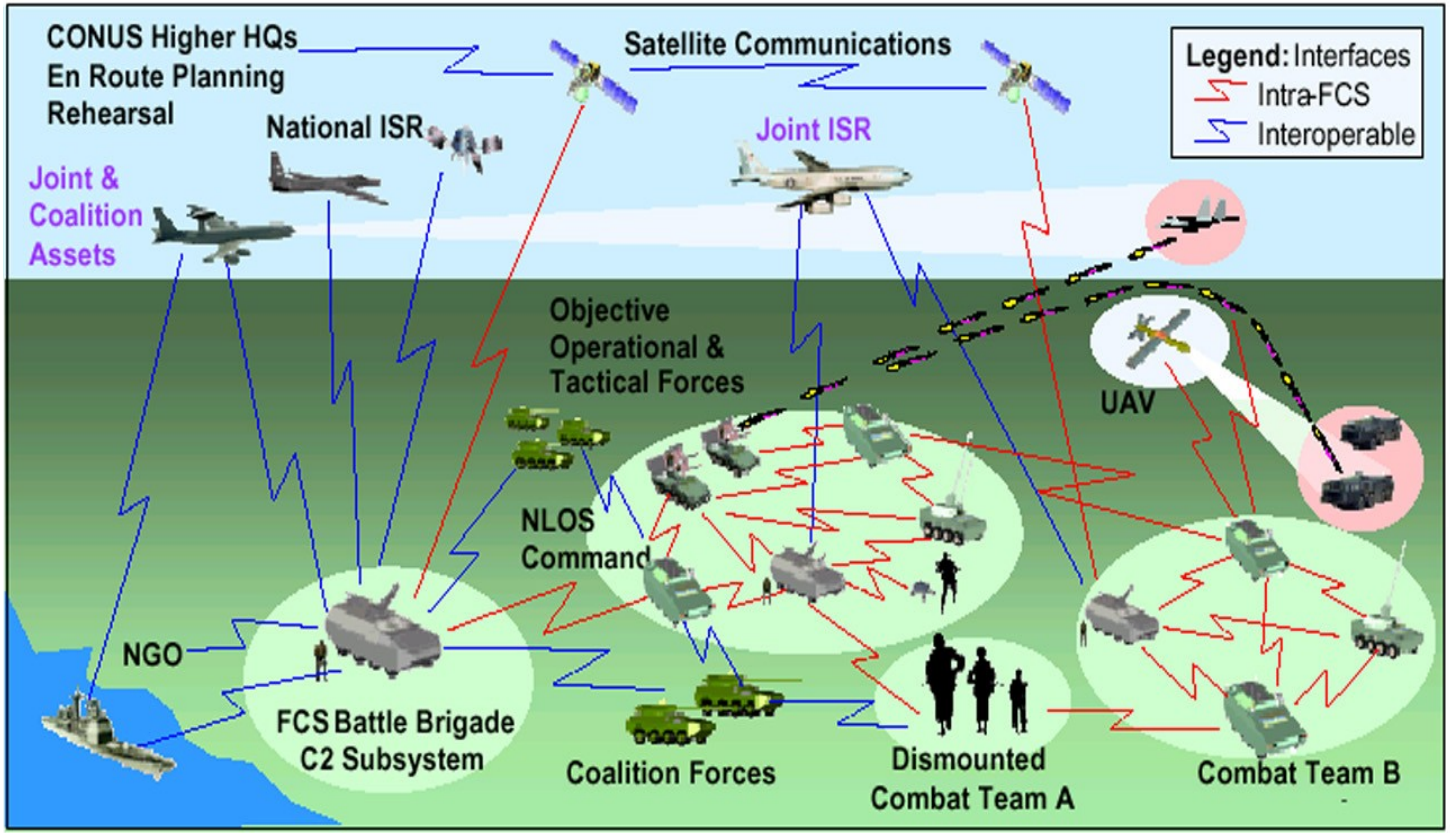

Potential Battlespace EMI / EMC Threats

- **All types of Radar**
- **Radio and Satellite Comms**
- **C4ISR Network**
- **Hostile Listeners**
- **Jammers**
- **Directed Energy Weapons**
- **Electromagnetic Pulse (EMP)**

EMI / EMC is real and is becoming more complex

How Does EMI / EMC Happen?

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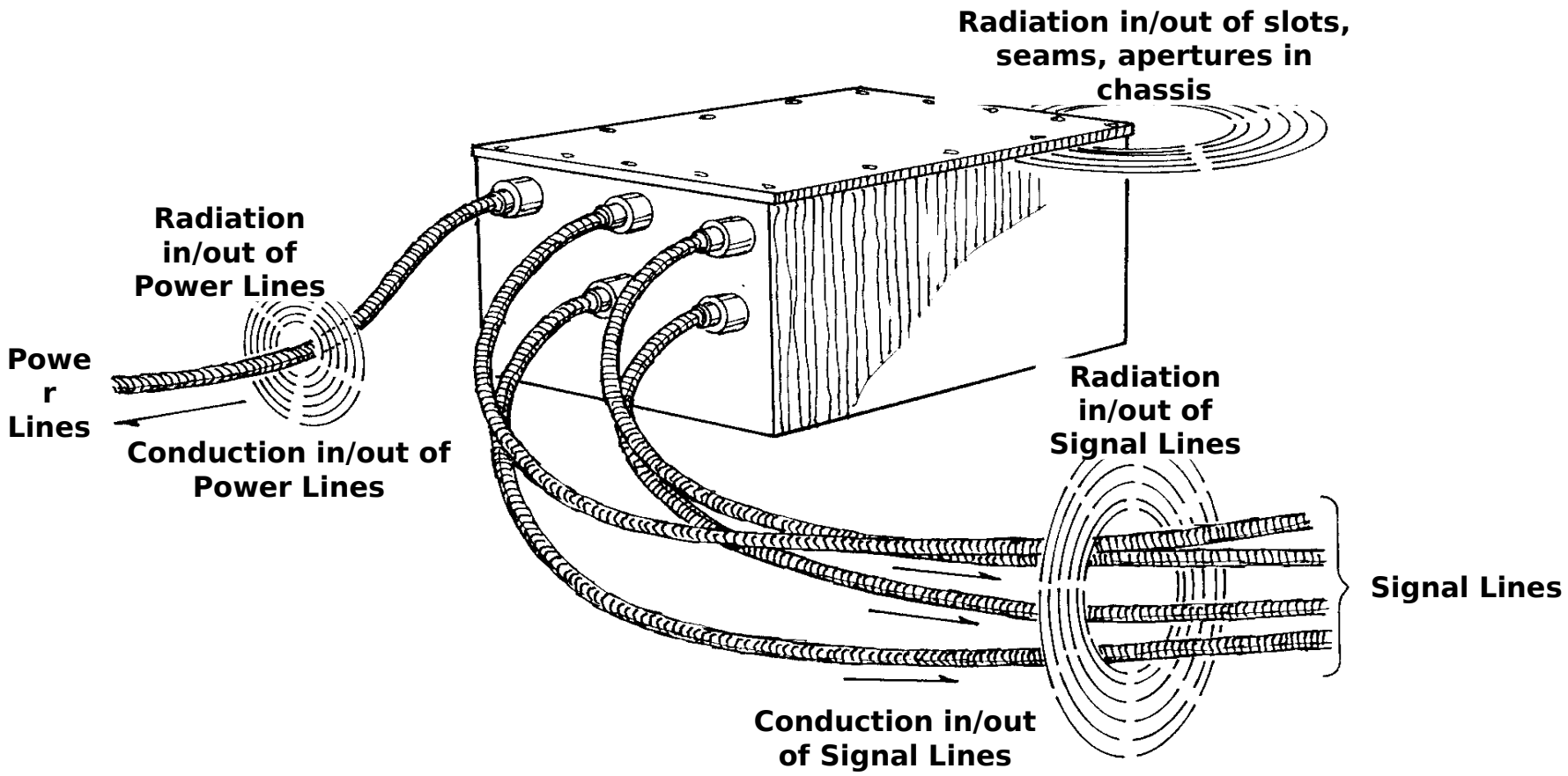
Radiation in/out of slots, seams, apertures in chassis
Radiation in/out of Power Lines
Power Lines
Conduction in/out of Power Lines
Radiation in/out of Signal Lines
Signal Lines
Conduction in/out of Signal Lines

Emissions - Noisy circuits inside radiate EMI from equipment
Susceptibility - Noise from outside leaks in and upsets sensitive circuits

EMI Specifications

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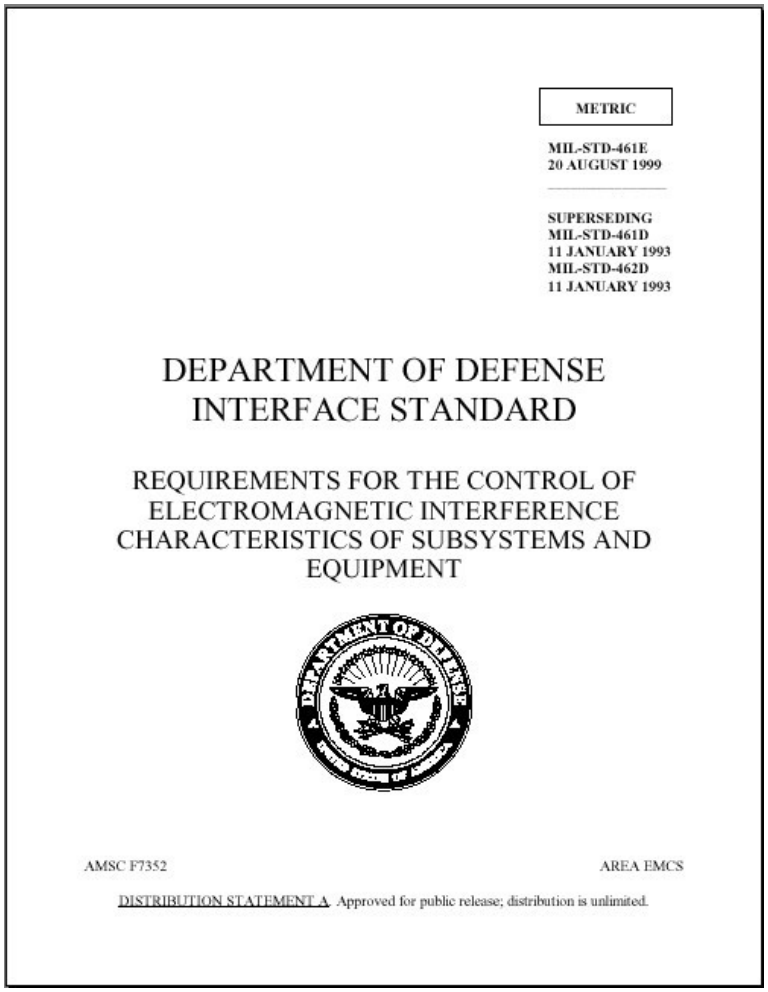

METRIC

MIL-STD-461E
20 AUGUST 1999

SUPERSEDING
MIL-STD-461D
11 JANUARY 1993
MIL-STD-462D
11 JANUARY 1993

DEPARTMENT OF DEFENSE
INTERFACE STANDARD

REQUIREMENTS FOR THE CONTROL OF ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS OF SUBSYSTEMS AND EQUIPMENT

AMSC F7352 AREA EMCS

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

Military

- MIL–STD–461E - EMI REQUIREMENTS, DESIGN and TEST
- MIL–STD–464 - VEHICLE EMC & LIGHTNING REQUIREMENTS

Commercial (Aircraft)

- RTCA–DO–160 - EMI & LIT REQUIREMENTS INCL TEST METHODS
- AC 20–136 - FAA LIT ADVISORY CIRCULAR

Commercial (Automotive, Consumer)

- SAE J551 (series of dash-specs)
- FCC Rules and Regulations, Title 47, Part 15, Subpart B
- European Union (Various)

FCS Requirements are very severe: MIL-STD-461E/464 “+”

Component Level Tests

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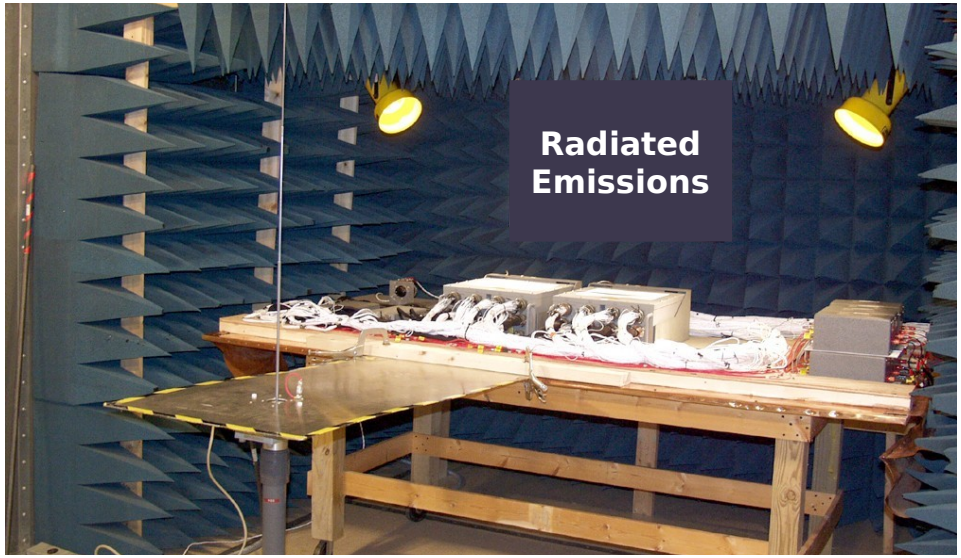

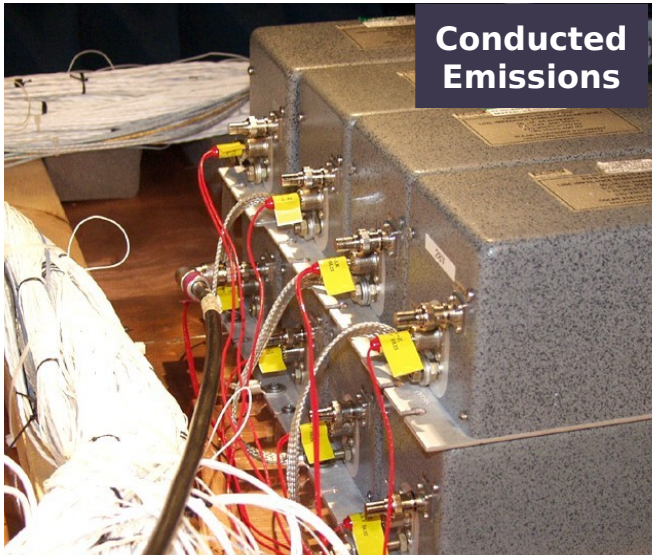

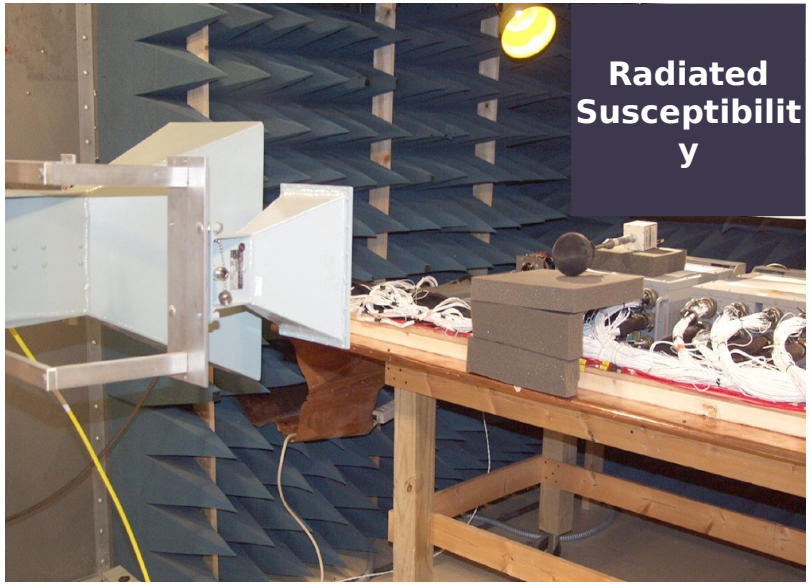

Platform Level Tests

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HybriDrive™ equipped bus at EMI/EMC test facility - Owego, NY

F/A-18 at EMI/EMC test facility - Patuxent River, MD

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Emissions Tutorial

How do I keep my equipment from emitting?

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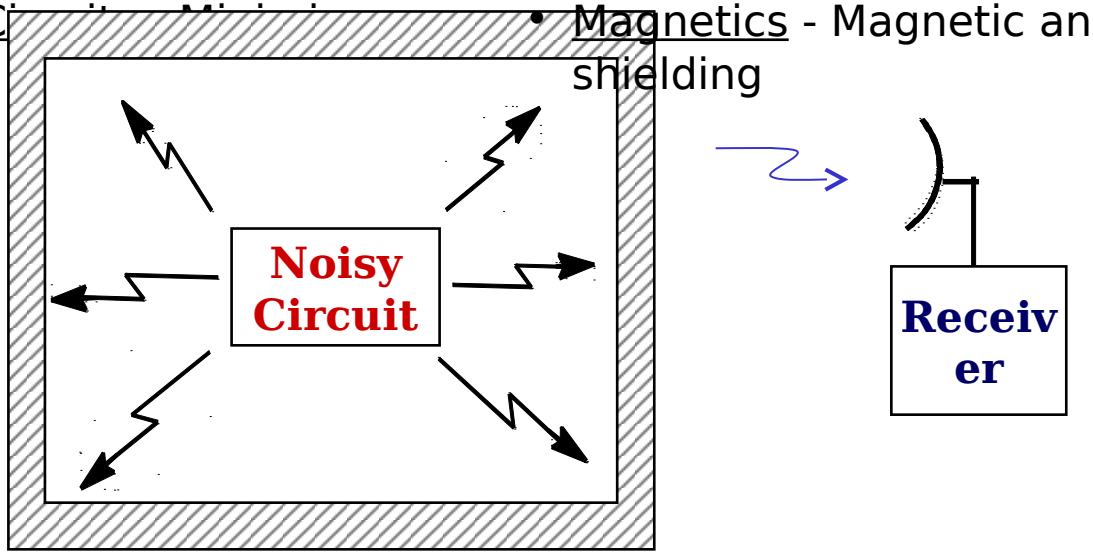
- Chassis Material - Highly conductive
- Chassis Joints - Tight and conductive
- Quiet Noisy Circuits - Minimize spikes
- Signal and power lines - Proper filtering
- I/O Cables - Shield with proper terminations
- Magnetics - Magnetic and electric shielding



Equipment Chassis

Minimize EMI generated and contain in the chassis

Noisy Power Supply

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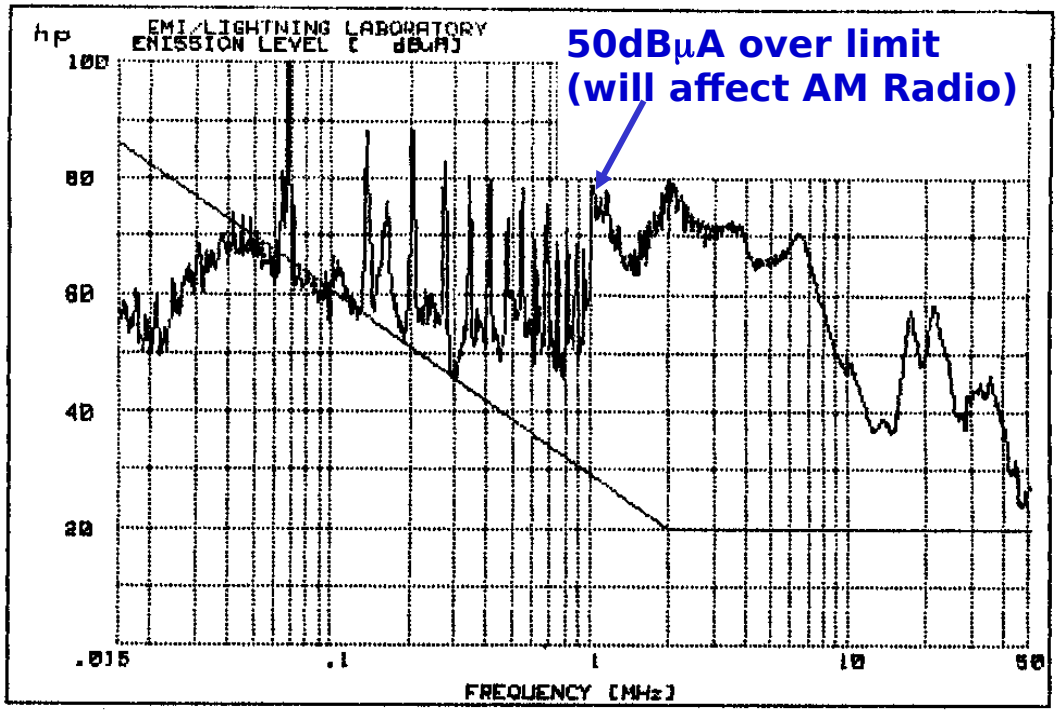

Problem: Primary noise source - Power supply switching (70kHz)

Symptom: Emissions such as these will walk all over AM radio signals

Solution: Suppress with common mode and differential mode power line filters

Noisy Circuit Emissions

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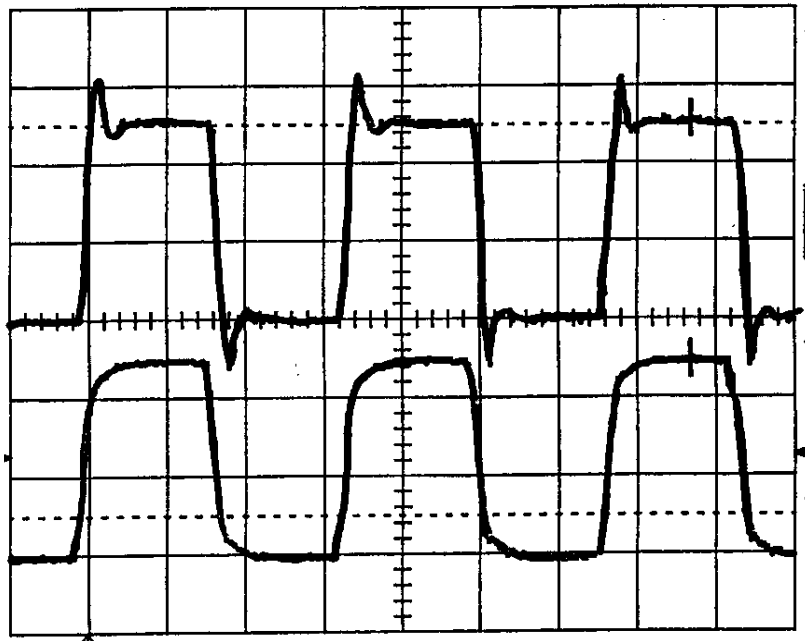

Noisy with harmonic rich ringing and overshoot

Clean with far less high frequency emissions

Problem: Noisy circuits couple common mode noise onto all signal lines

Symptom: Emissions affect FM radio signals

Solution: Clean up the ringing and add filter pins

Eliminate emissions at the source

Leaky Chassis

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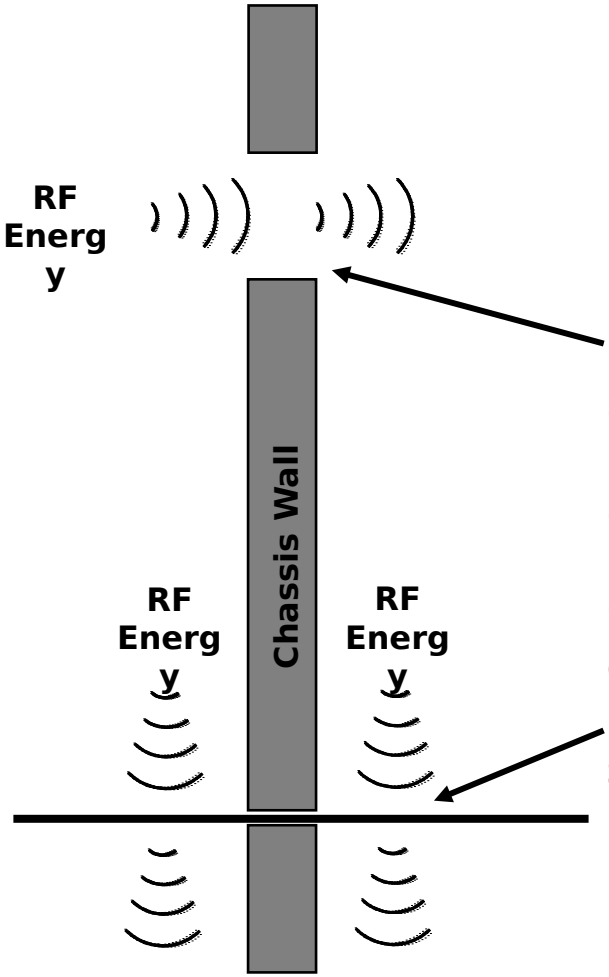

Problem: Slot in chassis or gap between cover screws
Symptom: Higher frequency emissions or susceptibility
Solution: Proper screw spacing, conductive gaskets

Problem: Wire through hole or unfiltered connector pin
Symptom: Lower frequency emissions or susceptibility
Solution: Filter pins, power line filtering

A single wire or slot can cause the problem

Results of Proper I/O Filtering

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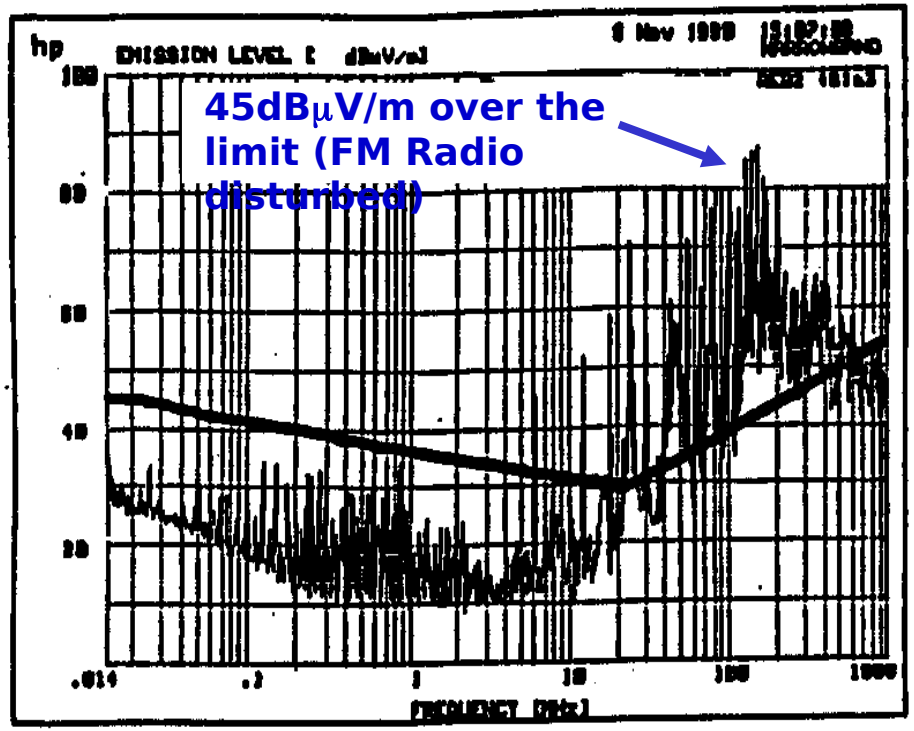
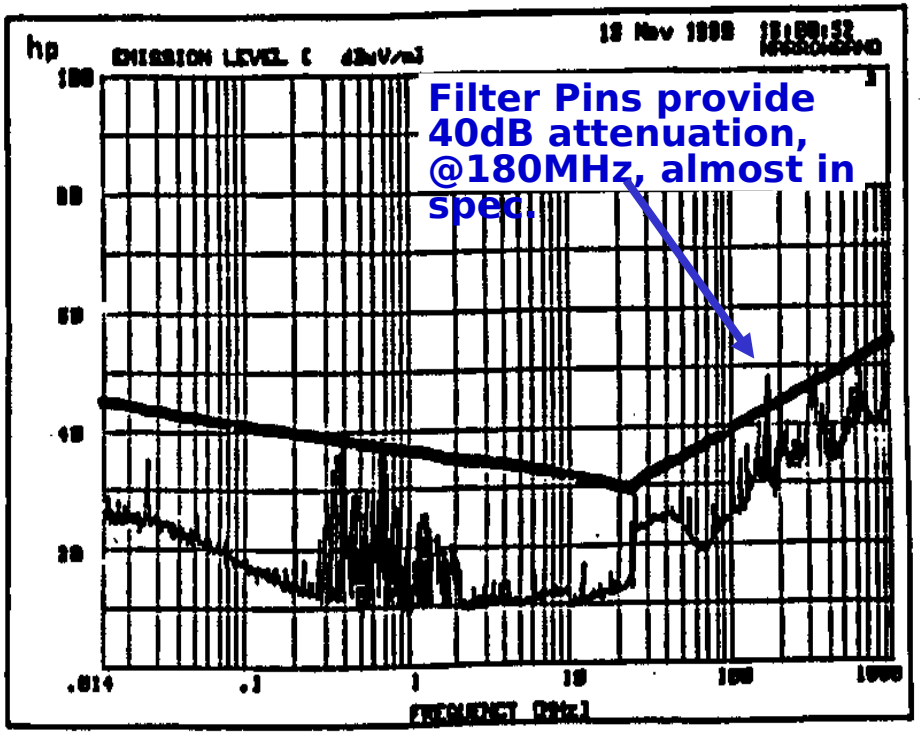


Before Filtering



After Filtering

I/O filtering must be considered during the design phase

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Susceptibility Tutorial

How do I avoid susceptibility?

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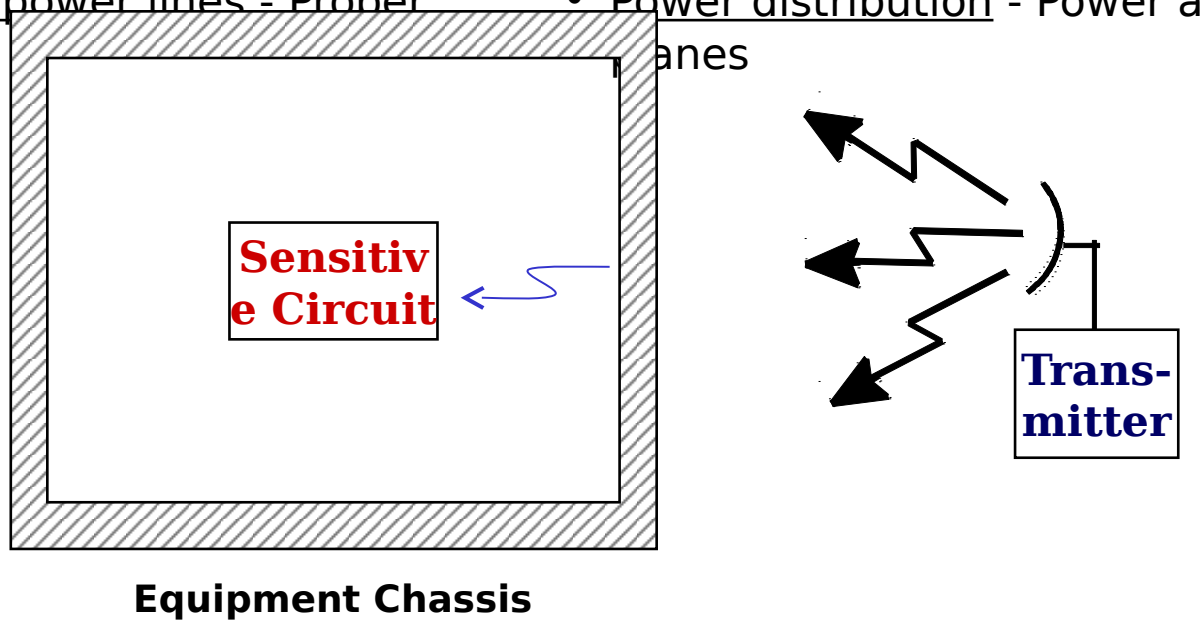
- Chassis Material - Highly conductive
- Chassis Joints - Tight and conductive
- Signal and power lines - Proper filtering
- Sensitive circuits - Bypass and in-line filtering
- I/O Cables - Shield with proper terminations
- Power distribution - Power and ground planes



Good design practice and experience leads to EMC

EMI Considerations for Hybrid Electric

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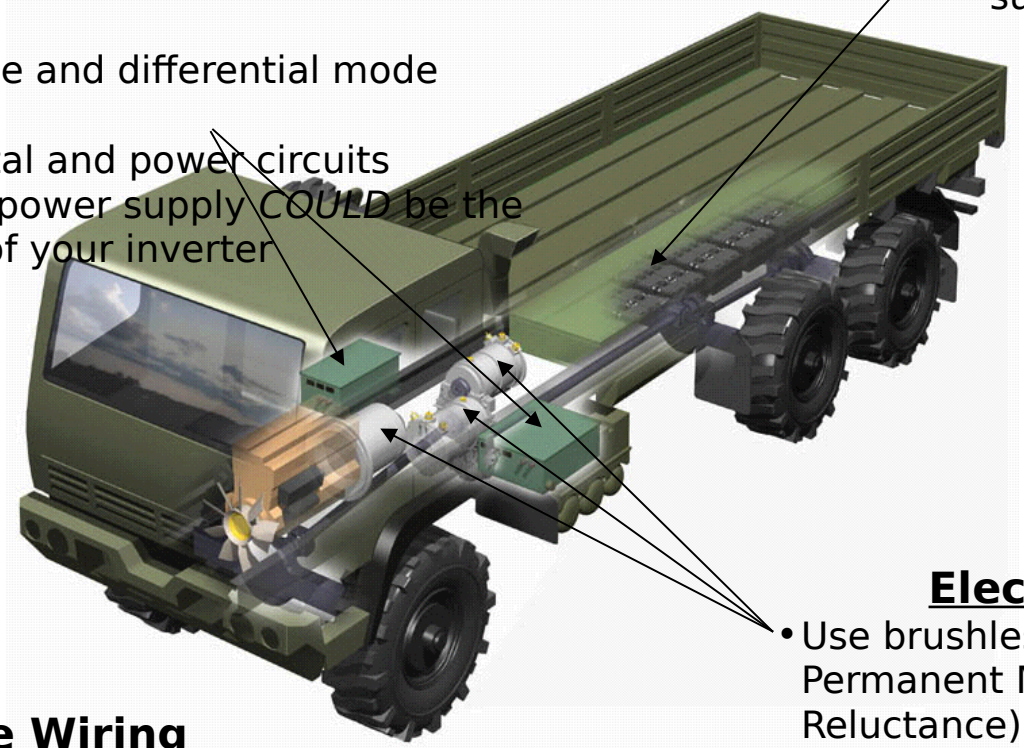
Power Electronics

- Use laminated buss bars
- Provide good high frequency DC-Link capacitors
- Snub high power switches to reduce ringing
- Common mode and differential mode filtering
- Separate digital and power circuits
- CPU and bias power supply *COULD* be the noisiest part of your inverter

Energy Storage System

- Battery management circuits can contain noisy elements such as processors



Electric Machines

- Use brushless types (AC Induction, Permanent Magnet, Switched Reluctance)
- Enclose high power terminals
- Common mode inverter noise
- Magnetic field radiation

Vehicle Wiring

- Overbraid high power bundles
- Shield digital data buses
- Provide proper shield terminations

Summary

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- All electrical systems are subject to EMI / EMC effects
- FCS requirements are much more severe than current day Tactical Wheeled Vehicles have been designed to meet
- EMI / EMC validation requires sophisticated procedures and equipment
- There are basic design practices that position the system designer to meet EMI / EMC specifications

With proper planning, FCS level EMI / EMC can be achieved within the C4ISR environment

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Backup

Overview of MIL-STD-461E

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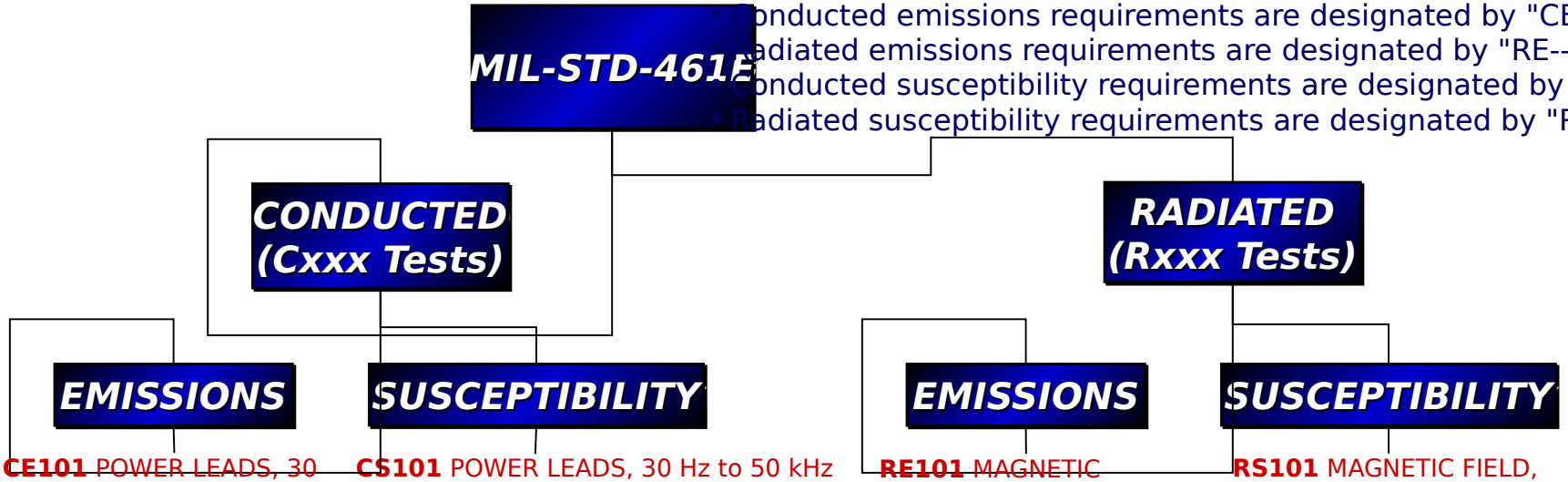
- Conducted emissions requirements are designated by "CE---."
- Radiated emissions requirements are designated by "RE---."
- Conducted susceptibility requirements are designated by "CS---."
- Radiated susceptibility requirements are designated by "RS---."



CE101 POWER LEADS, 30 Hz to 10 kHz

CE102 POWER LEADS, 10 kHz to 10 MHz

CE106 ANTENNA TERMINAL, 10 kHz to 40 GHz

CS101 POWER LEADS, 30 Hz to 50 kHz

CS103 ANTENNA PORT, INTERMODULATION, 15 kHz to 10 GHz

CS104 ANTENNA PORT, REJECTION OF UNDESIRED SIGNALS, 30 kHz to 20 GHz

CS105 ANTENNA PORT, CROSS MODULATION, 30 kHz to 20 GHz

CS109 CONDUCTED SUSCEPTIBILITY, STRUCTURE CURRENT, 60 Hz to 100 kHz

CS114 BULK CABLE INJECTION, 10 kHz to 400 MHz

CS115 BULK CABLE INJECTION, IMPULSE EXCITATION

CS116 DAMPED SINUSOIDAL TRANSIENTS, CABLES AND POWER LEADS, 10 kHz to 100 MHz

RE101 MAGNETIC FIELD, 30 Hz to 100 kHz

RE102 ELECTRIC FIELD, 10 kHz to 18 GHz

RE103 ANTENNA, SPURIOUS and HARMONIC OUTPUTS, 10 kHz to 40 GHz

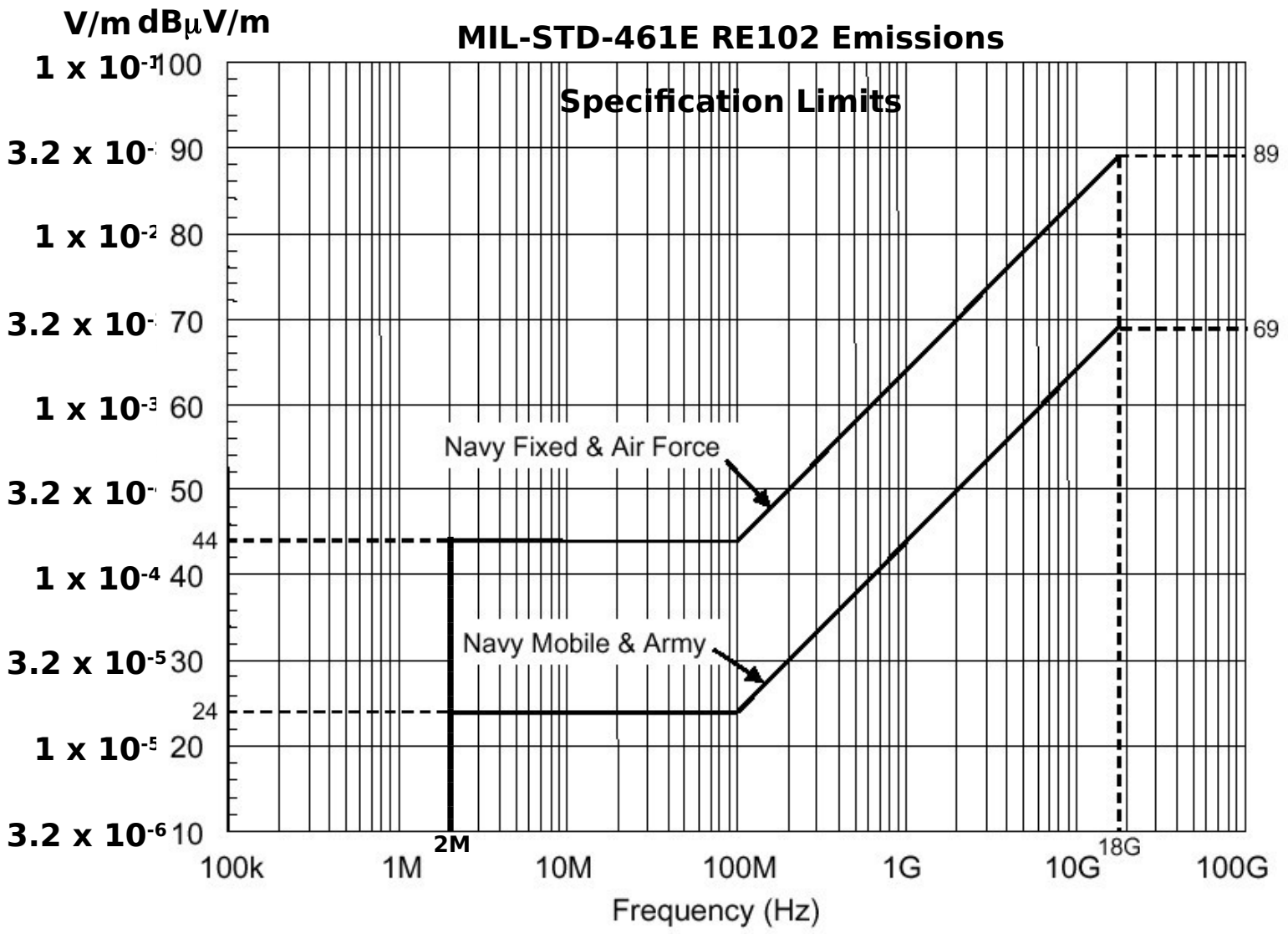
RS101 MAGNETIC FIELD, 30 Hz to 100 kHz

RS103 ELECTRIC FIELD, 10 kHz to 40 GHz

RS105 TRANSIENT ELECTROMAGNETIC FIELD

Common test groups for component level test shown in RED font

Typical Limit Line Nomenclature



Power Line Filtering

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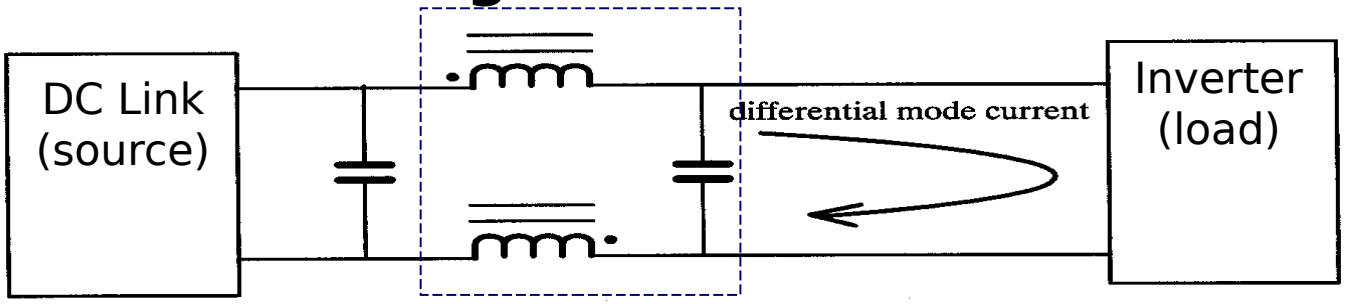
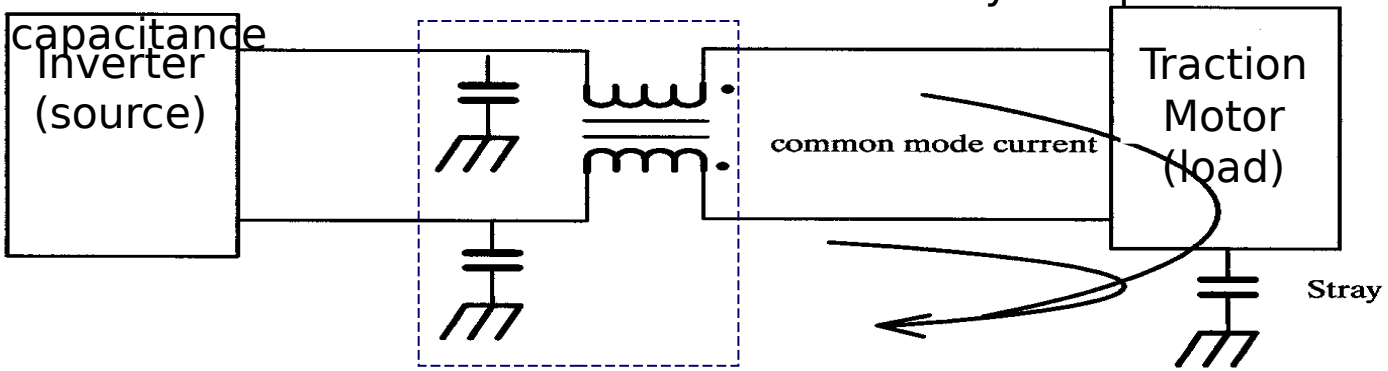


- Differential Mode noise goes out one wire and comes back on another
- Usually caused by Inverter or Power Supply pulse current drawn from source
- Block with Differential Mode Choke followed by adequate bulk capacitande



- Common Mode noise goes out both wires and comes back on the chassis
- Usually caused by high frequency power switches coupling to the heatsink
- Block with Common Mode Choke and high frequency capacitors to chassis

Circulate your pulse currents internal to your system

Filter Pin Connector

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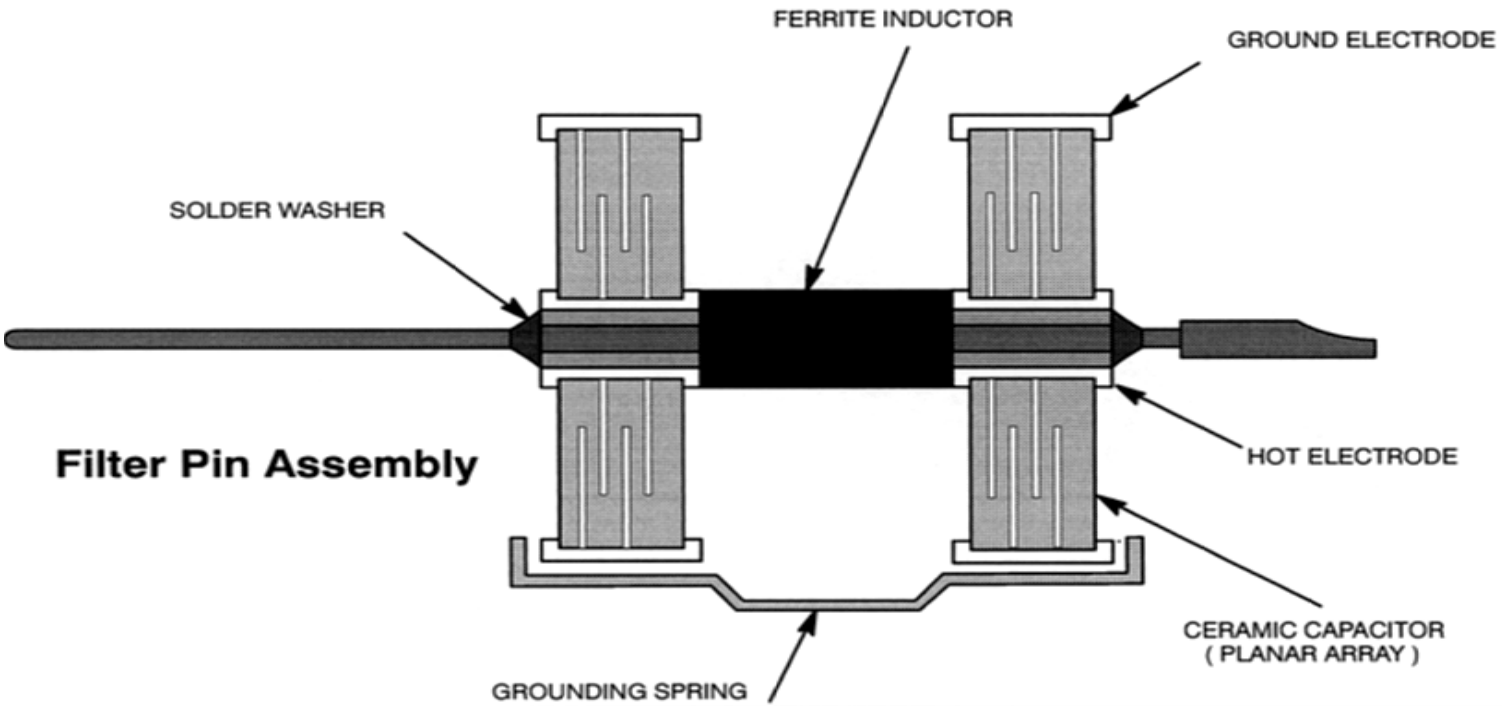

- Filter pin connector passes each I/O signal through a small high frequency π filter
- Effectively eliminates the shielding breach caused by wire-through-hole
- Filter loading can delay high impedance signals, alter analog control loop response and attenuate high frequency digital signals
- VERY Expensive, hard to test and can be damaged by lightning energy

Filter Pins work, but use with care!

How do I keep my equipment from emitting?

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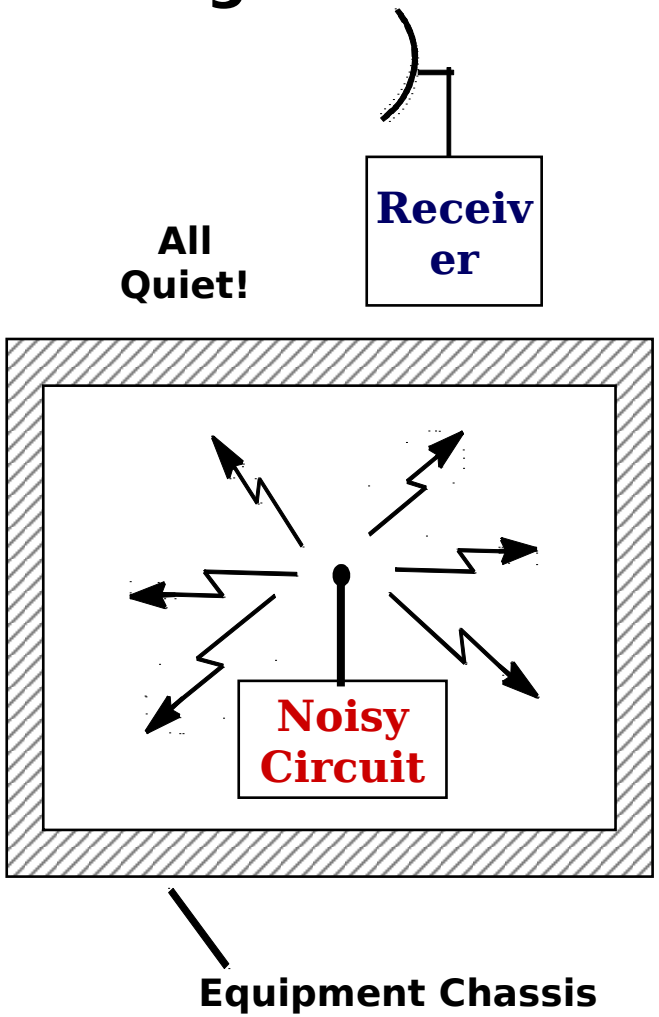

- Chassis Material - Highly conductive chassis or line plastic chassis with metal
- Chassis Seams and Lids - Provide tight, corrosion resistant Metal-to-Metal interfaces, use conductive gaskets or spring fingers, keep fastener spacing small or use lip seals
- Quiet Noisy Circuits - Minimize ringing and reflections, provide local decoupling capacitors for high frequency circuits, use laminated buss bars and snubbers with power switches to eliminate ringing and overshoot
- I/O Cables - Use common mode and differential mode power line filters, feed-through filter pins on I/O signals if needed, overbraid signals that are noisy by design (i.e. serial data buses)
- Magnetics - Transformer gap radiation, use belly band or encase in steel can. Faraday shield can help with common mode noise.

Don’t make much noise and keep the noise you make

What can you do about susceptibility?

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- Fix Leaky Packaging - Same guidelines as for emissions.
- Power and Ground - Use power and ground planes in circuit boards with localized power supply decoupling. Use a unipoint grounding scheme, avoid ground loops.
- Band-gap References - Decouple locally with high frequency (HF) capacitor, must use extremely short leads or the capacitor will be worthless.
- Sensitive Analog Circuits - Add HF capacitor (extremely short leads) across +/- input of op-amp. Op-amp power leads may require local HF decoupling. Rescale resistor networks to lower circuit impedance. Break into multiple, lower gain stages. Use differential configuration with lower gain on first stage from the connector pin. Avoid high impedance unity gain buffer configuration on input amplifiers. Use twisted, shielded wiring.
- Pulse Train Circuits - Use balanced differential input. Use a high amplitude transducer. Use lower input circuit impedance. Add hysteresis. Use twisted, shielded wiring.
- Cable Shielding - Overbraided cable bundles must be terminated with 360° connection to grounded connector backshell or overbraid will be worthless. Individually shielded signals must use very short shield termination wire or shield will be worthless.

May be able to desensitize before resorting to filter pins

EMI Considerations for Hybrid Electric

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